Appendix A

Advanced
Packaging

Discovering Gold as a Lead-free Substitute
By George A. Riley

The looming lead-free debacle is driving desperate alternative seekers to find proven lead-free flip chip bumping technologies. The leading candidate is gold bumping, which has a long history of high-volume production. Searchers first discovered the traditional advantages of gold bumps: fine pitch, high thermal and electrical conductivity, low creep, and high operating temperature ranges. Recent improvements have reduced gold bumping costs and broadened its range of applications.

Older gold bumping technologies, evaporation and electroplating, are based on vacuum systems and wet chemistry, respectively. Both require under-bump metallization and mechanical or photoresist masking.

Gold-stud bumping is a more recent development than evaporating or electroplating. A stud bump, also called a ball bump, is what remains of a gold wire-ball bond when the wire breaks. For stud bumping, the wire is deliberately broken just above the ball, leaving a gold sphere firmly micro-welded to the bond pad. While not matching the fine pitch of plated gold, stud bumping has its own advantages: no costly under-bump metallization; lower equipment cost without vacuum or wet chemical processes; low bumping and assembly temperatures; thermosonic gold-to-gold assembly or adhesive assembly; and bumping single die or bumping post-processed wafers having raised surface features, such as MEMS.

Improved stud bumping equipment and processes have lowered costs to make stud bumping the lowest-cost bumping method for many applications. Recent equipment improvements include higher throughput speed, finer bump pitch, and the ability to produce bumps in a variety of shapes.

Equipment manufacturers have nearly tripled the bump-placement rate from the original 12 bumps per second while accommodating 300-mm wafers. Automated wafer-handling equipment has been introduced to speed wafers through bumping equipment. These improvements have reduced time and increased throughput, which directly translates to lower costs.

As gold-ball wire bonders have moved toward finer pitches, gold-stud bumpers, which share bonder technology, have followed. Stud-bump pitches of 50 mm or less are possible with newer equipment. These permit higher density interconnection than conventional solder bumping. The fine pitch and low processing temperature makes stud bumping with adhesive connection competitive to indium for bumping large imaging arrays.

Because stud bumping is a serial process, the cost per wafer depends on the number of bumps. Wafer plating is a parallel process, with costs dependent on the material, bump height, and number of wafers plated. This makes gold-stud bumping the lowest-cost process for low-bump-count wafers.

Figure 1 shows total cost per bumped wafer vs. total number of bumps per wafer for four bumping technologies. The upper three bands in the figure are for plated bumping, where cost is independent of the number of bumps per wafer. In this model, 20-µm high-plated gold bumps are the most costly, reaching $120 per 200-mm wafer. Solder bumps are in the mid-range of $75 per wafer. Electroless nickel provides the lowest-cost plated bumps at $40 per wafer.

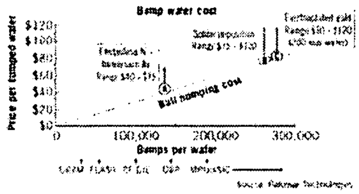

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Figure 1. *Ball bumping vs. plating costs.*

In Figure 1, stud-bumping cost is an upward-sloping line, increasing linearly with the number of bumps per wafer. It shows a lower cost than plating for bump counts below about 150,000 bumps per wafer. Common high-volume products include DRAM, flash memory, and RF die. Digital signal processors (DSP) are around the crossover cost point of 150k bumps per wafer. Below this, gold stud bumps have cost advantages over plating.

The advantages of stud bumps with gold-to-gold thermosonic interconnection have made it displace solder for packaging high-power, light-emitting diodes (LEDs). In this application, stud bumps demonstrate cost and performance advantages. The higher electrical conductivities of gold bumps compared to solder allows higher-current densities for increased light output. The higher thermal conductivity of gold carries heat away better than solder. The greater strength and higher operating temperature limits of gold increase device reliability. Lower processing temperatures for gold bumping and thermosonic interconnection permit continued use of present polymeric packaging materials for LEDs. The higher reflow temperatures of lead-free solder substitutes would require replacing these polymeric materials. The flux-free gold-to-gold system requires no aggressive cleaning and leaves no residue deposits on the optical surfaces.

Increasing capabilities, new applications, and the unforeseen consequences of the lead-free edict are making gold-stud-bump flip chip assembly a growing niche. Higher bumping speeds, with resulting lower cost, are allowing the natural advantages of gold to shine as a lead-free substitute.

References

Contact author for references.

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